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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G02B 27/22, H04N 13/00

A1

(11) International Publication Number: WO 99/08145

(43) International Publication Date: 18 February 1999 (18.02.99)

(21) International Application Number: PCT/GB98/02360

(22) International Filing Date: 6 August 1998 (06.08.98)

(30) Priority Data:
9716689.6 7 August 1997 (07.08.97) GB

(81) Designated States: CA, JP, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

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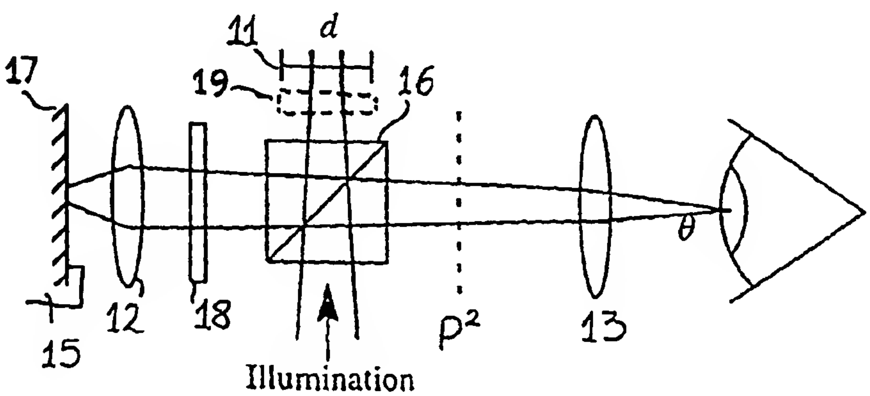
(54) Title: THREE DIMENSIONAL IMAGE DISPLAY



(57) Abstract

The 3-D image display consists of a pixellated display (11) that is illuminated through a beam splitter (16). A plan mirror (17) is provided on a movable mount (15) so that the mirror may be moved towards or away from an objective lens (12) positioned between the mirror (17) and the beam splitter (16). A quarter wave plate (18) is provided between the beam splitter (16) and the mirror (17) so that light reflected back from the mirror (17) through the quarter wave plate (18) passes straight through the beam splitter (16) to an eyepiece lens (13). Movement of the mirror (17) enables the mirror (17) to act as an optical path length modifier and permits an image from the display (11) to be presented at different focal positions. Rapid cycling through different focal positions results in the image being perceived as a 3-D image. As the objective lens (12) is positioned between the beam splitter (16) and the mirror (17), the objective lens (12) also acts as a demagnifying lens for images from the display (11). Preliminary demagnification of the image reduces the distances the mirror (17) is required to travel to provide the desired changes in focal position. This in turn reduces the demands on the performance of the mount (15), that are considerable in conventional systems where no demagnification is performed. In this way simple optical and mechanical components may be employed in the image display to generate perceived three dimensional images.

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THREE DIMENSIONAL IMAGE DISPLAY

The present invention relates to a three dimensional (3-D) image display of the type in which a series of two dimensional (2-D) images in different depth planes are presented in succession sufficiently rapidly that the series of images is perceived as a 3-D image. In particular, but not exclusively, the 3-D image display is suited for use in a stereo head mounted display system.

In general, for a head mounted display a pair of microdisplay devices, such as a feroelectric liquid crystal spatial light modulators (FLCSLM), are employed to display two images which are separately viewed through a series of lenses by each of the viewer's eyes so that the image is viewed at infinity or some other fixed distance. Figure 1 shows a conventional microdisplay projection system for one eye consisting of the FLCSLM 1, an objective lens 2 and an eyepiece lens 3. In practice a parallel lens system for the other eye would also be provided. The lenses provide the magnification necessary for the image displayed by the FLCSLM to be seen. In Figure 1, d denotes the size of an individual pixel of the FLCSLM which subtends an angle θ as seen by the viewer. Of course the image display system shown in Figure 1 is for the display of a two dimensional image. To enable this system to display 3-D images it has previously been suggested that one of the fixed lenses, preferably the objective lens, be replaced by a variable focus lens or in a folded system by a deformable mirror so that the image generate by the first FLCSLM may be presented to the viewer's eye sequentially at different focal positions and perceived as a 3-D image.

The present invention proposes an alternative display system which enables 3-D images to be perceived by a viewer which avoids the significant expense and other undesirable features of a variable focus lens or deformable mirror.

The present invention provides a 3-D image display comprising a display, a demagnifying lens for demagnifying an image generated by the display; a lens system for focussing the demagnified image and a controllable optical path length modifier for adjusting the optical path length through the image display whereby an image generated by the display can be focussed to sequentially appear at a plurality of different focal positions.

The optical path length modifier may be in the form of a drive unit for axially moving one or more optical components of the image display. Alternatively, the optical path length modifier may be in the form of a variable refractive index plate or an electro-optic modulator.

With the present invention, as the image generated by the display is initially demagnified, the variation in optical path length necessary to focus the image at appropriate focal positions is significantly reduced. In this way simple optical and mechanical components may be employed in the image display to generate perceived three dimensional images. Moreover, the 3-D image display is particularly suited to a head mounted display.

Embodiments of the present invention will now be describe by way of example only with reference to the accompanying drawings, in which:

Figure 1 is a diagram of a conventional image display system;

Figure 2 is a diagram of a first embodiment of a 3-D image display in accordance with the present invention; and

Figure 3 is a diagram of a second embodiment of a 3-D image display in accordance with the present invention.

In Figure 2 a modified version of the conventional image display system of Figure 1 is shown consisting of a FLCSLM 11, an objective lens 12 and an eyepiece lens 13 along with a demagnifying lens 14 located between the FLCSLM 11 and the objective lens 12. The demagnifying lens 14 generates a scaled down image in plane P^1 of the image generated by the FLCSLM 11. This demagnification is accommodated by the remainder of the lens system, lenses 12 and 13, which provides a greater

magnification than for the display system of Figure 1 so that the size of the image seen by the viewer is the same as for a conventional image display system.

In addition, it will be seen from Figure 2 that the objective lens 12 is housed in a piezoelectrically movable mount 15 which enables the objective lens 12 to be moved axially towards and away from the image plane P^1. The movable mount 15 or other suitable means provides a controlled movement of the objective lens along the axis of the display system.

With the image display shown in Figure 2, movement of the objective lens 12 towards or away from the image plane P^1 changes the apparent focal position of the image perceived by the viewer. For example, to achieved an apparent focal position of the image at a distance V from the viewer, the objective lens must be moved a distance Δ from the position of the objective lens where the image is projected at infinity, in accordance with the following approximate relationship:

$$\Delta = (M^2/V) . (d^2/\theta^2)$$

Where M is the magnification of the demagnifying lens 14. A similar effect can be achieved by mounting the eyepiece lens on the movable mount 15 and moving the eyepiece lens the same distance Δ or by moving both the FLCSLM and the demagnifying lens.

In this way, movement of the objective (or eyepiece) lens to different positions successively will present the 2-D images at different perceived distances and if this is done sufficiently quickly the viewer perceives the image as three dimensional. However, the objective lens 12 must be moved very quickly if the image perceived by the viewer is to be 3-D. To achieve a flicker free 3-D image a complete sequence of images at different perceived distances must be produced ideally faster than video rates, for example in less than 40ms. By demagnifying the image generated by the FLCSLM, the actual distance which the objective lens 12

must travel is scaled by a factor M^2 thereby making the generation of 3-D images in this manner feasible.

For example, without initial demagnification of the image produced by a conventional FLCSLM having 15 μm pixels (d=15 μm), to generate the image at a perceived distance of V=1 m with an angular extent of 30 degrees with 256 x 256 pixels, then θ=30°/256 and the objective lens would need to be moved by Δ=54 μm. To achieve a perceived distance of V=15 cm, an axial shift of the lens of Δ=360 μm would be needed. Although these axial distances are small, the lens must be move through these distances in a very short time. As an example, taking the greater distance of Δ=360 μm and allowing for only four separate perceived distances within the 40 ms time frame and with each image position held still for a period of time of 5 ms; the movement step would require a cycle of acceleration/deceleration of up to 57.6 m/s^2. This type of acceleration/deceleration and the resolution of the axial travel necessary for an operational imaging system, would be difficult to achieve with a mechanism which is sufficiently light and compact that it can form part of a head mounted display. By including initial demagnification of, for example, M=1/3, the axial shift for a perceived distance of 15 cm is reduced to 40 μm which in turn significantly reduces the necessary acceleration/deceleration requirements.

In Figure 3 a folded image display system is shown in which the microdisplay 11 is used in a reflective mode with a polarising beam splitter 16 provided between a polarised light source (not shown) and the FLCSLM 11. With this image display system the objective lens 12 also functions as the demagnifying lens with the image passing through the lens 12 to a mirror 17, which is mounted on the movable mount 15, and back through the lens.

In use, linearly polarised light passes through the beam splitter 16 and is reflected back by the FLCSLM 11. The reflected light from the

FLCSLM, which contains an image in light with polarisation rotated through 90°, is reflected by the beam splitter 16 through a quarter wave plate 18 towards the objective lens 12. The objective lens 12 demagnifies the image from the beam splitter 16 to produce a demagnified image in the image plane P^1. The mirror 17 placed at or near P^1 reflects the demagnified image back towards the objective lens 12 which refocuses the image to plane P^2. The double pass through the quarter wave plate 18 ensures that the polarisation of the image is rotated through 90° thereby ensuring the image passes straight through the beam splitter 16 to the eyepiece lens 13. With the mirror 17 at image plane P^1, the viewer perceives the image at infinity. Movement of the mirror 17 away from the image plane P^1 results in the image being perceived at a finite distance. Unlike the image display of Figure 2, as this is a folded optical system the mirror 17 need only be moved a distance $\Delta/2$ to achieve any desired perceived distance.

In an adaption of the optical arrangement shown in Figure 3, the polarising beam splitter 16 may be positioned adjacent the FLCSLM 11, off the main optical path through the apparatus, and the quarter wave plate 18 may be replaced with a non-polarising beam splitter, for example a pellicle beam splitter. With this adaption chromatic aberration can be reduced and the flexibility in the arrangement of the binocular display can be increased because the channels to each eye may be differentiated by polarisation, if it is so wished. The main disadvantage with this arrangement, however, is that around 75% of light is lost.

Furthermore, a pixellated shutter 19 such as an SLM may be included in the 3-D optical system. The SLM shutter 19 is indicated by broken lines in Figure 3. Particularly when the 3-D image display is used in a head mounted form, each pixel of display 11 contributes to one image plane and one plane only, because of the small angle of view. Hence, the display 11 can exhibit all the image planes at the same time. The SLM

shutter 19 is then used to transmit only the images from pixels of the display 11 appropriate for a particular plane. By synchronising the shutter action of the SLM shutter 19 with the movement of the mount 15, each image plane is transmitted cyclically by the shutter 19 to the eyepiece. This means that the display can be relatively slow (say 50 Hz, i.e. video rate) and rich in information (many colours, many grey levels) whilst the SLM shutter 19 operates at the much fast rate of the mount 15. Preferably, the SLM shutter 19 is positioned adjacent the display 11. However, there may be occasions where it is necessary to position the shutter away from the display, but still in an image plane of the display, in which case, the shutter must accommodate any changes in magnification of the image.

With both of the display systems described above refocusing of the image perceived by the viewer is achieved by the mechanical axial shift of one or more of the optical components of the system, e.g. the objective lens (Figure 2) and the mirror (Figure 3). However, in each case the refocusing is achieved because the optical path within the display system has been lengthened or reduced by a distance Δ in that part of the display system where a demagnified real or virtual image is projected. Of course there are alternative ways in which the optical path can be altered without movement of the individual optical components of the system. For example, a variable refractive index plate may be introduced into the display system in the vicinity of P^1. The variable refractive index device may be, for example, in the form of an electro-optic modulator or may be a plate such as a glass disc with sectors of varying thickness which can be rotated to intersect the optical path through the display system in sequence thereby achieving the necessary sequential path length variations.

It will be apparent that the output aperture of the display system is limited in size which has the effect of restricting the position of the viewer's eye. However, this is not a problem where the image display is to be used as a head mounted 3-D display as the viewer's position relative to the

display is of necessity fixed. There is a secondary effect associated with the restriction on the size of the output aperture; as the exit pupil of the display system becomes smaller than the pupil of the viewer's eye, the apparent depth of focus will appear larger for all objects. With optical systems of the type described above based on a 'microscope' design, the size of the output aperture is limited by the aperture of the objective lens and the magnification and position of the eyepiece lens. Particular display system architectures may therefore be selected to optimise the output aperture as far as the viewer is concerned. Moreover, appropriate selection of the system architecture is also necessary to ensure that the angular field of view seen by the viewer is constant for all perceived distances.

It will, of course, be appreciated that limited or defective focusing of an individual's eyes can be corrected for, once the characteristics of the problem are known.

As the changes in the image depth are achieved by the linear movement or rotation of a single component, the resulting aberrations introduced as the image is refocused are low compared to conventional 3-D display systems. Also, in a linear system by ensuring initial demagnification of the image which reduces the distance it is necessary to move the optical element, the power consumption is reduced and the associated noise and vibration can be minimised. The display system has the further advantage that it has the potential to transmit 100% of the input light which is a great improvement over conventional systems which employ either a FLCSLM variable focus lens or deformable mirror both of which are inefficient. Moreover, with a FLCSLM acting as a variable lens, that part of the light which is not refocused can lead to degradation in image contrast. Conventional systems which employ a FLCSLM as a variable lens have a further disadvantage in that such systems suffer from achromatic aberrations which is not a problem of the display systems

describe above.

Although the 3-D image displays have been described with reference to a head mounted display, of course the image displays are suitable for use in other applications such as in opthalmology equipment or indeed in any circumstances where rapid refocusing of images is required.

CLAIMS

1. A 3-D image display comprising a display, a demagnifying lens for demagnifying an image generated by the display, a lens system for focussing the demagnified image and a controllable optical path length modifier for adjusting the optical path length through the image display whereby an image generated by the display can be focussed to sequentially appear at a plurality of different focal positions.

2. A 3-D image display as claimed in claim 1, wherein the optical path length modifier is in the form of a variable refractive index plate or an electro-optic modulator.

3. A 3-D image display as claimed in claim 1, wherein the optical path length modifier is in the form of a drive unit for axially moving one or more optical components of the image display.

4. A 3-D image display as claimed in claim 3, wherein the drive unit is piezoelectrically operable.

5. A 3-D image display as claimed in either of claims 3 or 4, wherein the drive unit includes a mount in which one or more elements of the focusing lens system is mounted.

6. A 3-D image display system as claimed in any one of the preceding claims, wherein the image display system is folded and includes a polarising beam splitter, a mirror and a retardation plate positioned between the beam splitter and the mirror.

7. A 3-D image display system as claimed in claims 5 and 6, wherein the mirror is mounted on the drive unit.

8. A 3-D image display system as claimed in any one of claims 6 or 7, wherein the demagnifying lens is also the objective lens of the focusing lens system.

9. A.3-D image display as claimed in any one of the preceding claims, wherein the display is a spatial light modulator.

10. A 3-D image display as claimed in claim 9, wherein a pixellated shutter is provided for transmitting images from pixels of only one image plane.

11. A 3-D image display as claimed in claim 10, wherein the pixellated shutter is a spatial light modulator.

12. A head mounted display including the 3-D image display as claimed in any one of the preceding claims.

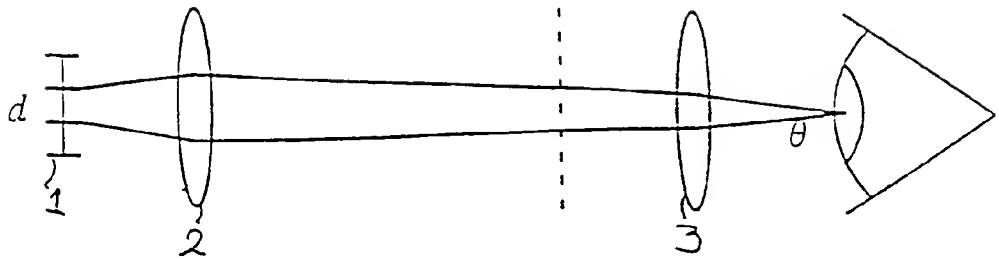

FIGURE 1

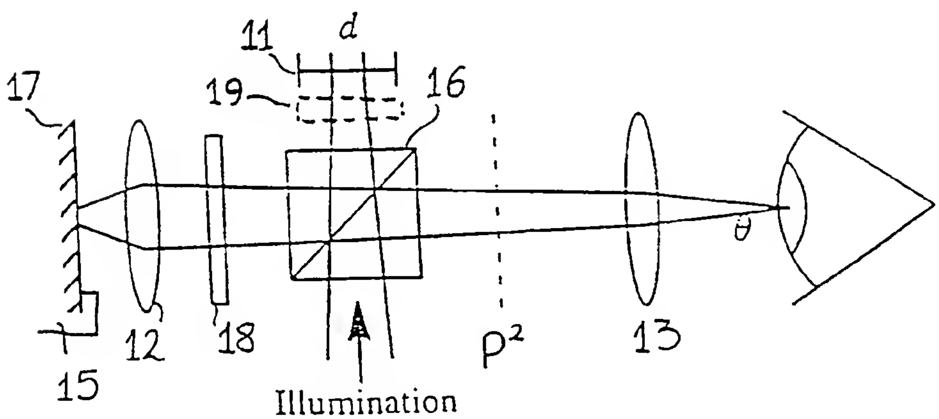

FIGURE 3

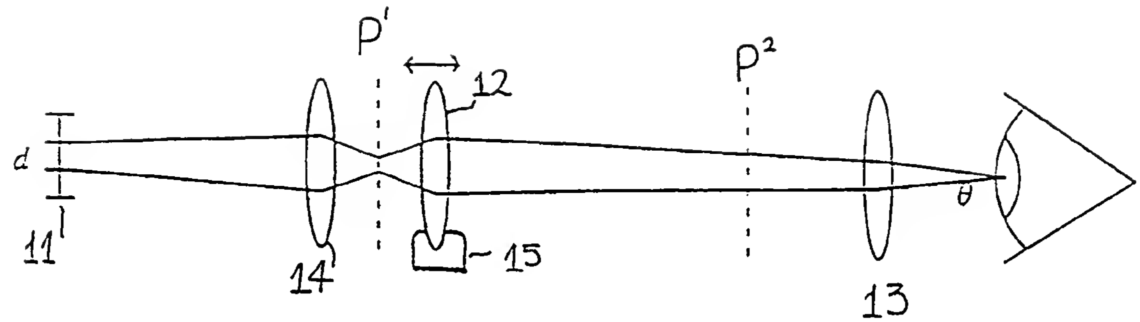

FIGURE 2

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 98/02360

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B27/22 H04N13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 84 04193 A (BRUKER MEDIZINTECH) 25 October 1984 see page 10 - page 16; figures 1,2	1,3,5,7, 8
A	EP 0 785 457 A (NIPPON TELEGRAPH & TELEPHONE) 23 July 1997 see column 36 - column 37; figures 40,42	2
A	EP 0 385 705 A (TEXAS INSTRUMENTS INC) 5 September 1990 see column 8; figure 1	1,9-11
A	WO 93 21673 A (BANDGAP TECH CORP) 28 October 1993 see column 7, line 30 - column 8, line 31; figure 2	12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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10 November 1998	17/11/1998

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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